National Aeronautics and
Space Administration

R&D Accomplishments

The Path to Innovation: Advancing Space Technology Through Success and Failure

Internal Research and Development Program Achievements

2018

A Report from the Goddard Office of the Chief Technologist

Goddard Space Flight Center
Greenbelt, Maryland

www.nasa.gov

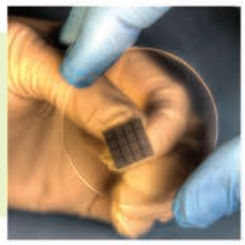
what's inside

2018 key achievements at-a-glance

Goddard planetary scientists were thrilled with New Frontiers mission selections in FY18, and for good reason. Both finalist teams involve significant participation from Goddard personnel. Danny Glavin and his team are developing important hardware for CAESAR, one of the finalist teams. See page 13.

NICER/SEXTANT is a gift that keeps giving. In addition to gathering data about neutron stars with its array of X-ray mirrors shown here, the mission last year demonstrated X-ray navigation using the same equipment. In 2019, NICER will demonstrate yet another first — X-ray communications. See page 9.

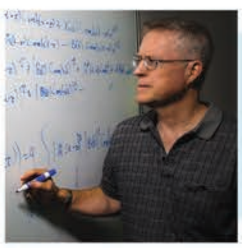
Nithin Abraham collaborated with the Smithsonian Institution in FY18 to determine if the patent-pending Molecular Adsorber Coating reduced the presence of contaminants in specimen-storage cabinets. See page 19.



A cross-disciplinary scintillator/silicon photomultiplier technology is central to a number of CubeSat instruments, including a miniature neutron spectrometer that Principal Investigator Georgia de Nolfo built for the Ionospheric Neutron Counter Analyzer (INCA), which is launching in early 2019. See page 10.

Virtual and augmented reality (VR/AR) are changing the way Goddard works. Principal Investigator Thomas Grubb has created a common infrastructure called the Mixed-Reality Engineering Toolkit that is making it easier for engineers to use this technology in their work. See page 18.

Twenty-plus years after scientist Bryan Blair conceived the idea of using a homegrown laser-based instrument to get a 3-D view of Earth's forests, he got a chance to fly the concept. In late 2018, the Global Ecosystems Dynamics Investigation, or GEDI, launched to the International Space Station. See page 7.



Michael Krainak won the FY18 IRAD Innovator of the Year for his visionary leadership and skill in applying emerging, potentially revolutionary technologies to a myriad of high-impact, agency-priority spaceflight needs. See page 27.

ONE

A Message from the Chief Technologist:

Recognizing the Value of Strategic Risk

If Thomas Edison had let failure define him, we could be living by candlelight. If Henry Ford had given up, horses could have remained our primary form of transportation. If Alexander Graham Bell had not persevered, the palm-sized gadgets we cannot live without today may never have been invented. The lightbulb, affordable automobiles, and telephones did not happen overnight. They required repeated experimentation to become a reality.

For organizations and individuals who dare to be bold, triumph and failure as well as strategic risk-taking should be expected and accepted. Failure is really the process by which we learn and overcome challenges.

We at Goddard are fortunate that our leadership and researchers understand this reality. One good idea, initially funded through Goddard's Internal Research and Development (IRAD) and Center Innovation Fund (CIF) programs, could ultimately lead to a revolutionary new technology that keeps NASA at the forefront of scientific discovery and exploration. Another may miss the mark entirely. But in R&D, setbacks do not equal failure; they lead to new insights, new knowledge and understanding.

In FY 2018, the value of risk taking and ostensible failure — or better yet, learning — became abundantly clear.

A Serendipitous Discovery

One research scientist, for example, had conceived a new technique for measuring an atmospheric chemical that determines the lifetime of methane. In testing, however, he discovered an artifact that prevented him from gathering the measurement. Despite the disappointment, he still succeeded. He serendipitously discovered that his instrument was extremely sensitive to ozone. In fact, it is nearly 100 times more sensitive than commercially available instruments. His "failure" resulted in the filing of a patent application and an improved way to more accurately measure another important atmospheric molecule.

Challenges also beset the team that built, launched, and now operate the Dellingr CubeSat mission, which was developed with IRAD program funding. Shortly after Dellingr deployed, the spacecraft began to spin, which prevented its miniaturized mass spectrometer from collecting data. Instead of declaring mission failure, the team wrote new software, uploaded it, and used one of Dellingr's magnetometers as an attitude sensor, which provided data needed to activate the spacecraft's torquers and stabilized the spinning. For this reason, among others, the Office of the Chief Technologist bestowed its FY18 IRAD Team award to the Dellingr team (see page 28).

Michael Krainak, a prodigious innovator and thinker at Goddard, certainly appreciates the value of risk taking. The FY18 IRAD Innovator of the Year has proven the value of staying current with emerging technologies and applying this knowledge to the development of laser- and electro-optical-based capabilities. Do all of his ideas work as conceived? No. The point is, he does not give up. He innovates and actively pursues IRAD and other funding programs to advance his ideas (see page 28).

Fortunately for Goddard, Dellingr team members and Michael Krainak are not unique in their risk taking. In FY18, our IRAD innovators used their funding to incubate ideas, never fearing failure. Many then secured millions of dollars in follow-on funding, secured launch opportunities aboard sounding rockets, balloons, and the International Space Station, and won Phase-A and other mission studies. Still others reached the pinnacle of their journey by winning new missions and instrument opportunities.

In this report, we highlight and celebrate our researchers' creativity and achievements and their search for knowledge.

Peter Hughes
Chief Technologist
Goddard Space Flight Center

The First Step: A Strategic Alignment of Goddard's Lines of Business

TWO

We believe the first step in the path to success for both Goddard's Internal Research and Development (IRAD) and Center Innovation Fund (CIF) programs is our methodology — the focus and discipline we employ to identify investment priorities, unmet needs, and target opportunities.

Selection Criteria for IRAD and CIF

Under the IRAD program, for example, we fund only those efforts that map to one or more goals of Goddard's strategic lines of business, which align with NASA's goals via the National Research Council's decadal surveys. All proposals go through a rigorous review. We adhere to strict selection standards and require principal investigators to compete for their awards.

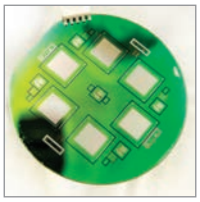
For NASA's CIF, we award research dollars only to proposals that demonstrate technical merit, feasibility, relevance, and value to NASA. All are highly innovative, crosscutting, and considered early stage in their development. Many also leverage partner resources and have the potential to contribute significantly to national needs.

Astrophysics

Focuses on missions and technologies enabling the study of the physics and origin of our universe and everything in it, including galaxies, stars, exoplanetary systems, and the search for potential life beyond our own solar system.

Communications and Navigation

Supports systems and technologies needed to communicate with space-based missions and navigation.



Crosscutting Technology and Capabilities

Develops capabilities applicable to more than one strategic line of business, everything from nanomaterials and electronics to detectors and system architectures.

Earth Science

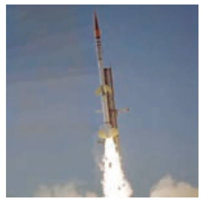
Supports technologies and advanced science instruments needed to observe and understand changes in Earth's natural systems and processes, including climate, severe weather, the atmosphere, the oceans, sea ice and glaciers, and the land surface.

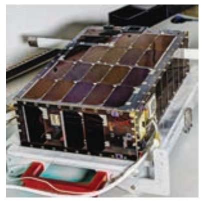
Heliophysics

Conducts research on the Sun, its extended solar-system environment (the heliosphere), and its interactions with Earth, other planets, small bodies, and interstellar gas.

Planetary Science

Supports technologies to explore the solar system, including instruments and spacecraft for landers, sample-return missions, and remote-sensing orbiting spacecraft to understand the formation of our solar system and determine the existence of past or current life.





Suborbital Platforms and Range Services/Science SmallSat Technology

Supports systems to advance the performance and efficiency of SmallSats, sounding rockets, balloons, and manned and unmanned aircraft as well as their payloads. Range services include assets for conducting, launching, and operating missions.

Breakdown of FY18 Awards

Goddard is an organization dedicated to discovery. It has proven adept at creating, fine-tuning, and adapting emerging technologies largely because the center focuses on strategic technological areas enabled by the skills of its diverse, adaptable workforce. Here is the breakdown of our FY18 allocations.

Significant Milestones: A Summary of FY18's Major Accomplishments

The goal of Goddard's Internal Research and Development (IRAD) and Center Innovation Fund (CIF) programs is providing initial seed funding for promising, sometimes risky technologies that have the potential to bring about revolutionary new ways to explore the world around us.

Our researchers typically follow a specific path to success. They flesh out their ideas with IRAD and CIF support, seek follow-on funding through other NASA funding programs, demonstrate their technologies in a space or near-space environment aboard sounding rockets, research aircraft, high-altitude balloons, CubeSats/SmallSats, ride shares, and the International Space Station. In the end, the goal is to infuse these technologies into new missions or instruments that broaden our understanding of the Sun, Earth, solar system, and universe beyond. Just as important is spinning off these space technologies to others who use them to solve challenges on Earth.

Year after year, our technologists hit these milestones. They embrace risk, learn from their research, and secure new instrument and mission starts as well as follow-on funding at levels that more than compensate for our initial investment in their technologies.

This chapter details some of those accomplishments as well as others that underscore our technologists' commitment to technology development and NASA's missions and goals..

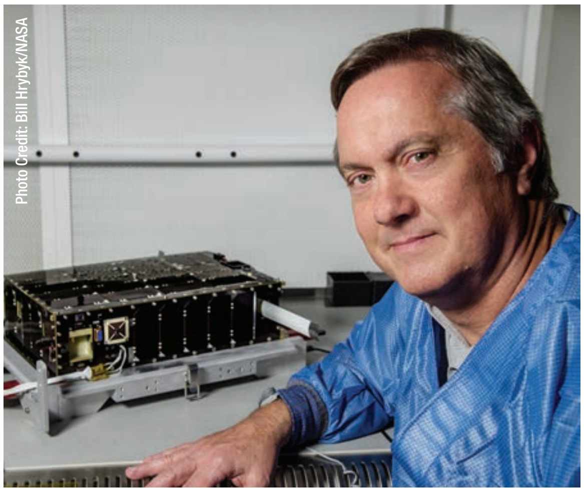
Launches and Flights

The pinnacle of success is the launch of new missions as well as technology-demonstration payloads aboard research aircraft, scientific balloons, and sounding rockets. In FY18, several IRAD-funded missions and technologies either deployed or received launch dates. Here is a summary of each.

Dellingr

The Dellingr-development team overcame budget and schedule constraints and potentially mission-ending challenges in FY18 to ultimately create a highly reliable and resilient CubeSat bus that is now collecting NASA-quality science and demonstrating important SmallSat engineering capabilities. Shortly after the 6U CubeSat deployed from the International Space Station in FY18, the team encountered difficulties that the team resolved through innovative thinking. The Dellingr-development effort mission contributed to the win of three additional CubeSat missions, including petitSat, GTOSat, and BurstCube, and efforts are now underway to create a follow-on SmallSat architecture — DellingrX — which will extend capabilities beyond CubeSats and be capable of operating outside the relatively benign radiation environment found in low-Earth orbit (see page 27 for details). (Investment Areas: Science SmallSat Technologies, Crosscutting Technology and Capabilities, and Heliophysics)

A SpaceX Falcon 9 rocket from the Kennedy Space Center carried the Goddard-developed Dellingr CubeSat to the International Space Station where it eventually was deployed in FY18.



The Dellingr spacecraft is a 6U CubeSat that deployed from the International Space Station in FY18. It is shown here with Dellingr Project Manager Chuck Clagett.

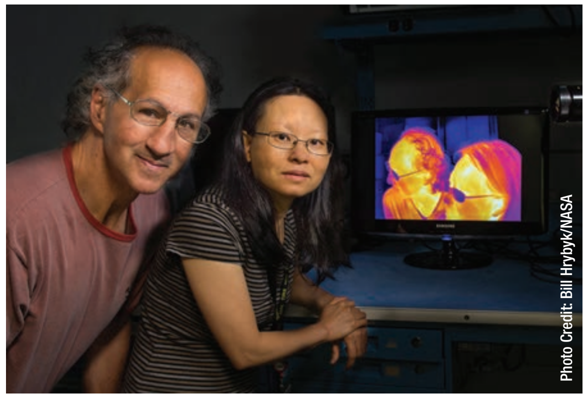
Global Ecosystem Dynamics Investigation (GEDI)

Twenty-plus years after scientist Bryan Blair conceived the idea of using a "homegrown" laser-based instrument to get a 3-D view of Earth's forests, he got a chance to fly the concept in 2018. The mission, called GEDI, launched to the International Space Station in December 2018 aboard a SpaceX vehicle. GEDI relies on lidar technology that Blair first developed in the 1990s for an aircraft instrument called the Land, Vegetation and Ice Sensor.
(Investment Area: Earth Science)

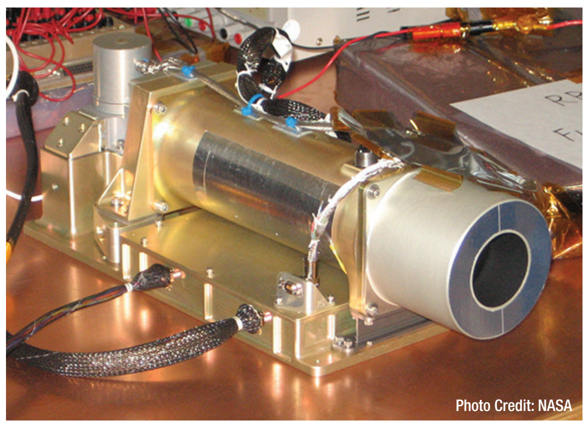
GEDI is shown here in a clean room. The payload launched to the International Space Station in December 2018.

RRM3 and Strained-Layer Superlattice (SLS) Detectors

Also launched aboard a SpaceX vehicle in early December 2018 was a next-generation camera — the Compact Thermal Camera — as part of NASA's Robotic Refueling Mission 3. Enabled by the relatively new SLS photodetector technology, the camera is designed to image and videotape Earth's surface with help from SpaceCube 2.0, a powerful hybrid computing system that is controlling the instrument and processing the images. The demonstration's goal is raising SLS's technology-readiness level to nine, meaning that it has flown in space and can operate in a space environment.
(Investment Areas: Earth Science and Crosscutting Technology and Capabilities)



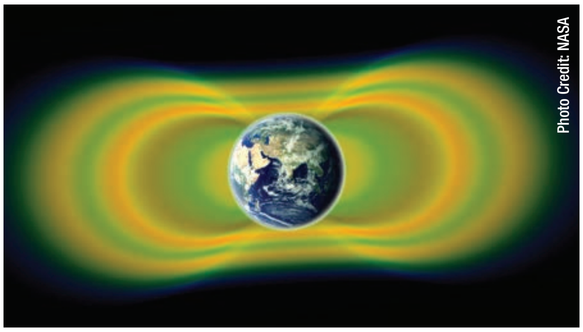
Goddard detector engineer Murzy Jhabvala (left) and his team, including Anh La (right) and Don Jennings (not pictured), advanced a new detector technology called Strained-Layer Superlattice. The team was expected to begin demonstrating the technology once it is deployed on the International Space Station in December 2018.



This image shows the advanced detector technology — Strained-Layer Superlattice — that will be demonstrated aboard the International Space Station.

Compact Radiation belt Explorer (CeREs)

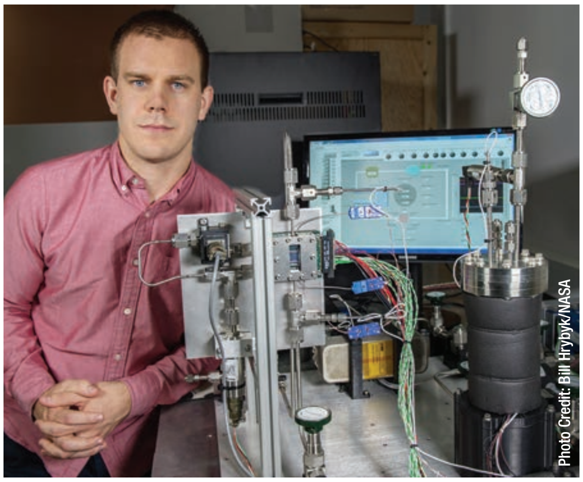
This 3U CubeSat is designed to study charged-particle dynamics in Earth's radiation belts using a novel sensor called the Miniaturized Electron and Proton Telescope. Developed initially with IRAD support, CeREs launched in December 2018 on the RocketLabs Electron rocket from New Zealand.
(Investment Area: Heliophysics)



CeREs will study charged-particle dynamics in Earth's Van Allen radiation belts. The CubeSat is expected to launch in December 2018 from New Zealand.

Micro-gap Cooling

An emerging technology for removing excessive, potentially damaging heat from small, tightly packed instrument electronics and other spaceflight gear is scheduled to launch aboard the Blue Origin New Shephard Launch Vehicle in late 2018. Led by Principal Investigator Franklin Robinson, the demonstration goal is proving that the micro-gap cooling technology is immune from the effects of gravity.
(Investment Area: Crosscutting Technology and Capabilities)



Technologist Franklin Robinson is expected to demonstrate his micro-gap cooling technology aboard the Blue Origin New Shephard Launch Vehicle in late 2018. He is shown here with his testbed.

Visualizing Ion Outflow via Neutral Atom Sensing-2 (VISIONS-2)

Scheduled for a late 2018 launch, the VISIONS-2 sounding-rocket mission is designed to investigate the outflow of oxygen ions from Earth's upper atmosphere and into the magnetosphere during the day from Earth's magnetic cusps. Led by Principal Investigator Doug Rowland, VISIONS-2 is flying four IRAD-funded instruments and experiments, including the Experimental-Energetic Neutral Atom Imager developed by Principal Investigator Nikolaos Paschalidis; an internal magnetometer developed by Principal Investigators Eftyhia Zesta and Todd Bonalsky; the compact Acute Precipitating Electron Spectrometer, advanced by Marilia Samara; and the Cubesat Electric Field Instrument built by Rowland and Robert Pfaff.
(Investment Area: Heliophysics)

Mini-Carb

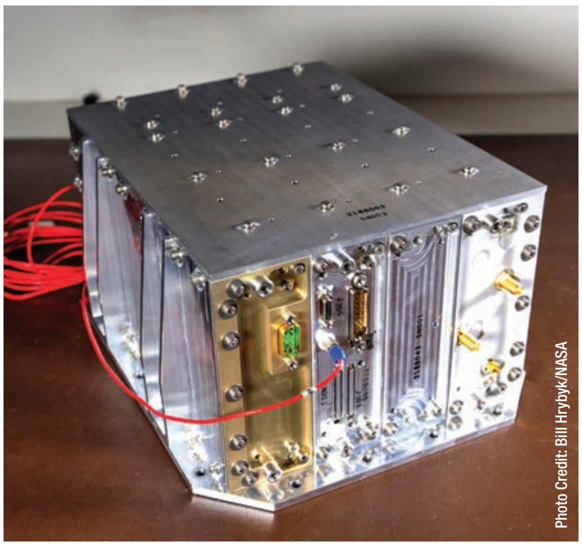
Mini-Carb is a CubeSat collaboration between Principal Investigator Emily Wilson and the Lawrence Livermore National Laboratory (LLNL). Scheduled to launch in January 2019, the LLNL-developed 6U CubeSat will carry a toaster-sized version of Wilson's patented mini-Laser Heterodyne Radiometer, which she has tested extensively in field campaigns to measure greenhouse gases. The Mini-Carb instrument will measure carbon dioxide, methane, and water vapor from space.
(Investment Area: Earth Science)

Technologists integrate a Goddard-developed instrument into Lawrence Livermore National Laboratory's CubeSat bus. The CubeSat is expected to launch in January 2019.

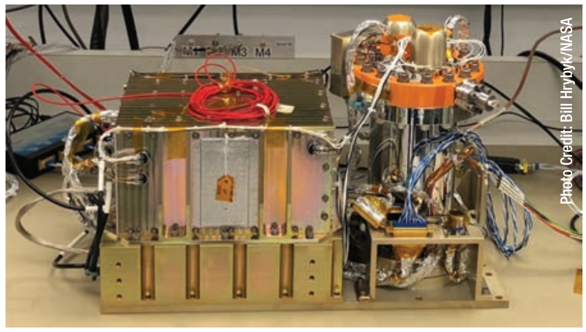
X-ray Communications Using the Neutron Star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT)

NICER/SEXTANT is a gift that keeps giving. Already gathering data about neutron stars and demonstrating the effectiveness of X-ray navigation (see page 17), the mission will show another first early next year — X-ray communications (XCOM). To carry out the XCOM experiment, the NICER/SEXTANT team is deploying its Modulated X-ray Source (MXS) on the orbiting outpost in February 2019. Developed to calibrate the mission's X-ray detectors and test X-ray navigation algorithms, the MXS will transmit digitally encoded data on pulsed X-rays and transmit the data to NICER/SEXTANT's receivers.
(Investment Area: Communications and Navigation)

In a related development, Principal Investigator Munther Hassouneh completed the development of the NavCube GPS L1/L2C receiver hardware and flight software, which will be used in the XCOM demonstration that will happen aboard the International Space Station early next year. If successful, the demonstration will raise NavCube's technology-readiness level to nine.
(Investment Area: Communications and Navigation)



NavCube, the product of a merger between the Goddard-developed SpaceCube 2.0 and the Navigator GPS technologies, is playing a vital role demonstrating X-ray communications in space.



The Modulated X-ray Source will fly to the International Space Station in February 2019 to demonstrate X-ray communications.

Doppler Wind Lidar Measurements and Scalability to Space

Principal Investigator John Yorks, who used his FY18 IRAD funding to improve both the Aircraft Cloud-Aerosol-Transport System's (ACATS) ability to measure wind speed/direction and explore other telescope options, is expected to fly the instrument on an Earth Resources-2 research aircraft in early 2019. ACATS led to the development of a space-based instrument that retired late last year after spending 33 months aboard the International Space Station.
(Investment Areas: Earth Sciences)

The Aircraft Cloud-Aerosol-Transport System will fly aboard NASA's ER-2 research aircraft in early 2019.

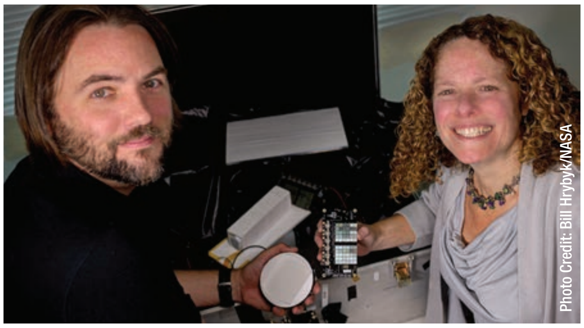
Electrically Driven Liquid Film Boiling in Absence of Gravity

Principal Investigators Jeffrey Didion and Jamal Yagoobi, experts in fluid-based cooling technologies, will fly their electrically driven liquid film boiling experiment aboard a NASA research aircraft in Spring 2019. The three-day effort will support a similar-type experiment on the International Space Station and was designed to advance cooling technologies that promise less mechanical complexity and maintenance.
(Investment Area: Crosscutting Technology and Capabilities)

Ionospheric Neutron Counter Analyzer (INCA) and Scintillator/Silicon Photomultiplier Technology

A miniature neutron spectrometer created by Principal Investigator Georgia de Nolfo will fly on the INCA mission in March 2019. Developed by New Mexico State University-Las Cruces, INCA will study the latitude and time dependencies of the neutron spectrum in low-Earth orbit. Central to de Nolfo's instrument is a scintillator/silicon photomultiplier applicable to all types of cross-disciplinary scientific investigations, including a recently awarded CubeSat mission called **BurstCube**.

INCA and BurstCube, however, are not the only beneficiaries of de Nolfo's work. She has completed the testing of large-area photomultiplier arrays for a National Science Foundation-funded CubeSat called **Terrestrial RaYs Analysis and Detection (TRYAD)**, now being built by the University of Alabama-Huntsville and Auburn University. Just as exciting, the arrays are being tested with a heavy ion beam at the **CERN facility** in an opportunity that is expected to raise the technology's readiness level for flight applications.
(Investment Area: Heliophysics)



BurstCube Principal Investigator Jeremy Perkins and his co-investigator, Georgia de Nolfo, are using a silicon photomultiplier array that de Nolfo developed. The same technology will fly on the INCA mission set to launch in March 2019.

Balloon-borne Investigation of Temperature and Speed of Electrons in the corona (BITSE)

Principal Investigators Nat Gopalswamy and Jeffrey Newmark plan to fly BITSE aboard a high-altitude scientific balloon from Ft. Sumner, New Mexico, in the fall 2019. BITSE is equipped with a new type of coronagraph that can measure three important processes — the density, temperature, and speed of electrons in the corona — necessary for understanding the formation of the solar wind. Ultimately the team wants to fly the instrument on the International Space Station.

In a related effort, Principal Investigators Joseph Davila and Nicholeen Viall redesigned and used **3-D printing to manufacture a small coronagraph** — an effort designed to decrease instrument costs and complexity, while increasing performance. As a result of their work, the BITSE team will use the 3-D printed parts to fit check BITSE's optical alignment procedures.
(Investment Areas: Heliophysics)

Goddard heliophysicists Jeff Newmark (left) and Nat Gopalswamy plan to fly BITSE aboard a high-altitude scientific balloon from Ft. Sumner, New Mexico, in the fall 2019. Here, Gopalswamy holds the polarization camera he developed for the mission.

Principal Investigators Pat Haas (left) and Nicki Viall, who exhibited their work at the FY18 IRAD Poster Session in October 2018, redesigned and used 3-D printing to manufacture a small coronagraph. The BITSE team will use the parts to fit check BITSE's optical alignment procedures. Photo Credit: Bill Hrybyk/NASA

Balloon-Borne Cryogenic Telescope Testbed (BOBCAT)

Principal Investigator Al Kogut developed an ultra-lightweight, highly innovative dewar for cooling far-infrared telescope components — a technology he believes could enable Great Observatory-type science aboard scientific balloons. He is scheduled to test the technology during two balloon missions from Palestine, Texas, in the spring and summer of 2019. With additional NASA investments, Kogut wants to combine the cooling technology with a miniaturized spectrometer to provide the first science demonstration. (Investment Area: Astrophysics)

Receive System for Multiple Payload Swarm (RSMPS)

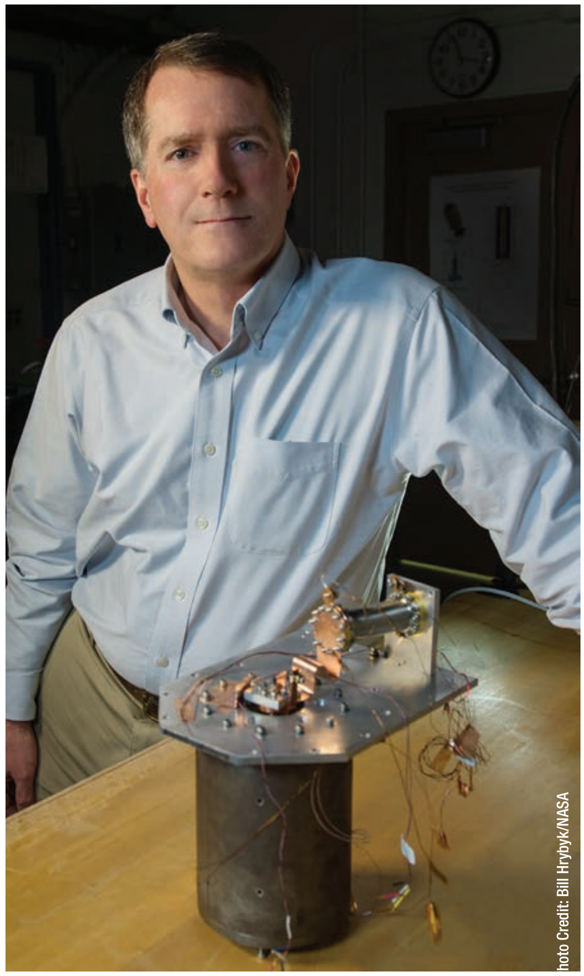
Principal Investigators Christian Amey and Brian Banks are set to demonstrate a system for receiving and decoding transmitted data from multiple deployable communications systems. The Sounding Rocket Program Office at the Wallops Flight Facility, which is excited about the future of this technology, has committed resources for testing this swarm communications technology on a sounding-rocket mission in mid-2019.

Award of New Missions, Instrument Opportunities, and Technology Breakthroughs

Another significant measure of success is whether an IRAD-funded effort leads to the award of or infusion into a new mission. In FY18, Goddard teams received funding to develop two CubeSat-related missions and one team's technology was baselined for a future mission. They also secured flight opportunities and demonstrated breakthrough measurements with laboratory instruments.

Experiment for Cryogenic Large-Aperture Intensity Mapping (EXCLAIM)

EXCLAIM, led by Principal Investigator Eric Switzer, will map the history of star formation across cosmic time. The balloon payload, which is expected to begin gathering science in 2022, is earmarked to receive funding to carry out the investigation, which includes several other Goddard technologies: MicroSpec, a spectrometer-on-a-chip developed by Harvey Moseley and Emily Barrentine and the Continuous Adiabatic Demagnetization Refrigerator. Switzer also will employ an observing technique conceived by Al Kogut for his BOBCAT balloon mission (see item on the left). (Investment Area: Astrophysics)



EXCLAIM, led by Principal Investigator Eric Switzer, will map the history of star formation across cosmic time. The balloon payload, which is expected to begin gathering science in 2022, will use the Goddard-developed Continuous Adiabatic Demagnetization Refrigerator, which is shown here with Goddard cryogenic engineer Jim Tuttle.

GTOSat

Principal Investigator Lauren Blum won funding to develop a 6U CubeSat mission — GTOSat. This mission of firsts, which Blum and her team expect to launch in early 2021, will serve as a pathfinder for new radiation-tolerant technologies that could help scientists realize a long-sought dream of deploying a constellation of small satellites beyond low-Earth orbit. It will also be the first to use the new DellingrX SmallSat architecture. Once in orbit, GTOSat will use its two onboard instruments to

Story continued on page 12

measure high-energy particles that likely originate from solar wind and cosmic rays.
(Investment Area: Heliophysics)

Meanwhile, the GTOSat mission baselined a miniaturized fluxgate magnetometer developed by Principal Investigator Jared Espley, who used his FY18 IRAD to develop the instrument's sensor and a radiation-hardened compact electronics package. GTOSat is the first mission to use Espley's technology.
(Investment Area: Astrophysics)

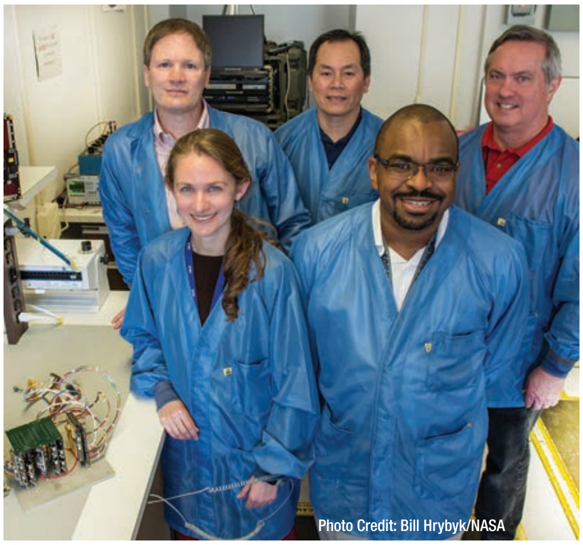


Photo Credit: Bill Hrybyk/NASA

Scientist Lauren Blum and her team won funding to develop GTOSat, which will fly radiation-tolerant technologies. The CubeSat is expected to launch in early 2021. From left to right (back): Larry Kepko, Hanson Nguyen, Chuck Clagett; (front): Blum and James Fraction.

SigNals-of-Opportunity (SNoOPI): P-Band Investigation

SNoOPI will be the first on-orbit demonstration of P-band signals of opportunity for discerning soil moisture levels two-to-four inches below the surface — two to four times deeper than current soil-moisture-measurement missions. SNoOPI, which involves several Goddard technologists, including Co-Investigator Jeff Piepmeier, received funding to build a CubeSat that would demonstrate the technology and measurement technique. Led by Purdue University James Garrison, the mission is expected to launch in 2021.
(Investment Area: Earth Science)

Beam-Plasma Interactions Experiment

Robert Pfaff, Doug Rowland, and two other Goddard scientists are collaborating with Geoff Reeves, a researcher at the Los Alamos National Lab (LANL), to develop an experiment testing the physics of beam-plasma-wave interactions aboard a sounding rocket. The experiment, is expected to launch from the Wallops Flight Facility in 2021. The primary rocket payload consists of an electron accelerator, while the daughter payload, which separates from the mother, includes 3-D electric probes, magnetic search coils, a waveform-capture radio receiver, a Langmuir probe, and an electron detector.
(Investment Area: Heliophysics)

Daytime Dynamo Rocket Investigation

Meanwhile, Principal Investigator Robert Pfaff also received funding to carry out a dual sounding-rocket investigation of the ion-neutral coupling, winds, and electrodynamics that govern the global atmospheric dynamo that flows at the base of the daytime ionosphere. The experiment includes several Goddard-developed instruments as well as several provided by the Aerospace Corporation. The rockets will be launched in 2020 from the Wallops Flight Facility.
(Investment Area: Heliophysics)

Loss Through Auroral Microburst Pulsations (LAMP)

Led by Principal Investigators Sarah Jones and Nick Paschalidis, LAMP is a sounding-rocket mission that will provide the first simultaneous in-situ measurements of pulsating auroral and microburst electron thrust. According to the principal investigators, LAMP is a vital first step in quantifying the role of the aurora in magnetospheric electron loss. Expected to launch in 2020 from Poker Flats in Alaska, the sounding rocket will carry several instruments from Goddard, the University of New Hampshire, the Japanese Space Agency, and Dartmouth College.
(Investment Area: Heliophysics)

Very Low Frequency (VLF) Trans-Ionospheric Propagation Experiment Rocket (VIPER)

Scientist Marilia Samara is collaborating with John Bonnell, a researcher at the University of California-Berkeley, to develop a rocket experiment investigating VLF trans-ionospheric propagation. This measurement is intrinsically important from a plasma-electrodynamics perspective, but also to scientists' understanding of terrestrial space weather in general and radiation belt dynamics in particular. The experiment, is expected to launch in the summer of 2020.
(Investment Area: Heliophysics)

Award of Phase-A and New Mission Studies

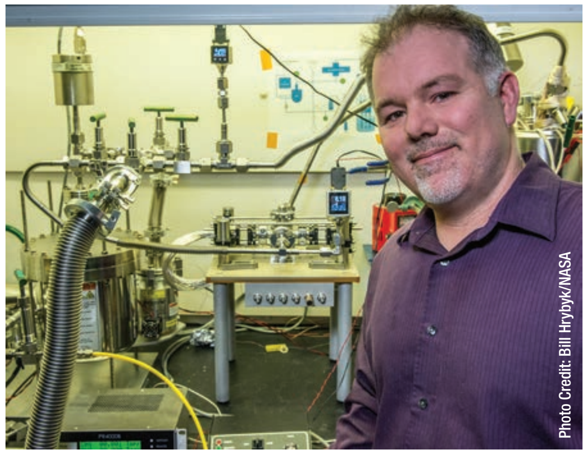
Another significant measure of success is whether an IRAD-funded effort leads to the award of a Phase-A or another type of mission study. In FY18, Goddard teams were involved in several.

New Frontiers Phase-A Studies

Goddard planetary scientists were thrilled with NASA's New Frontiers mission selections in FY18, and for good reason. Both finalist teams involve significant work involving Goddard personnel and two others, also involving Goddard experts, received technology-development funding to reduce risks. All four received IRAD seed funding for instrument development and mission formulation.
(Investment Area: Planetary Science)

Below are summaries of the missions:

- **Comet Astrobiology Exploration Sample Return (CAESAR)**
  CAESAR is one of the finalists for NASA's next \$1-billion New Frontiers mission, which NASA is expected to choose mid-2019. CAESAR, which Goddard would manage if selected, will send a spacecraft to comet 67P/Churyumov-Gerasimenko and scoop up nearly three ounces of material. CAESAR's Goddard-developed instruments then would separate the volatiles from the solids and deliver the samples to Earth for analysis.

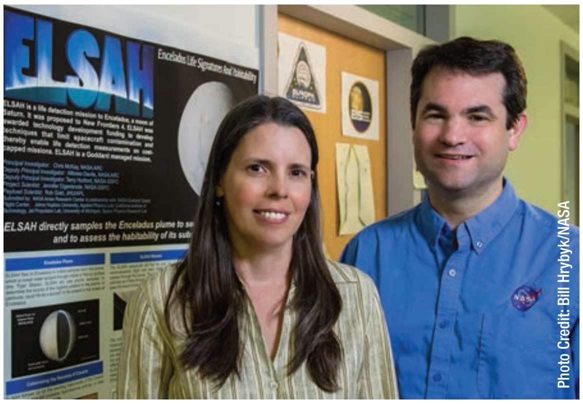


Scientist Danny Glavin used FY18 IRAD funds to advance a gas-transfer system and a water-vapor sensor for CAESAR, selected in FY18 for a Phase-A New Frontiers study.

- The Johns Hopkins University-led **Dragonfly** is the other finalist. It would launch a rover-type vehicle to investigate the prebiotic chemistry and habitability of dozens of sites on Saturn's moon, Titan. It, too, features a Goddard-developed instrument, a mass spectrometer, to identify the chemical components on the surface.

One of two finalists in the New Frontiers competition — Dragonfly — would investigate prebiotic chemistry and habitability of multiple sites on Saturn's moon, Titan.

- **Enceladus Life Signatures and Habitability (ELSAH)** is one of two to receive technology-development funding. This mission would use a Goddard-developed mass spectrometer to study the plumes coming from about 100 sites on Enceladus, a small but geological active moon that could harbor a subsurface ocean.



Jen Eigenbrode and Terry Hurford are part of a team that proposed ELSAH under NASA's New Frontiers competition. The team is receiving technology-development funds to advance contamination-control technologies.

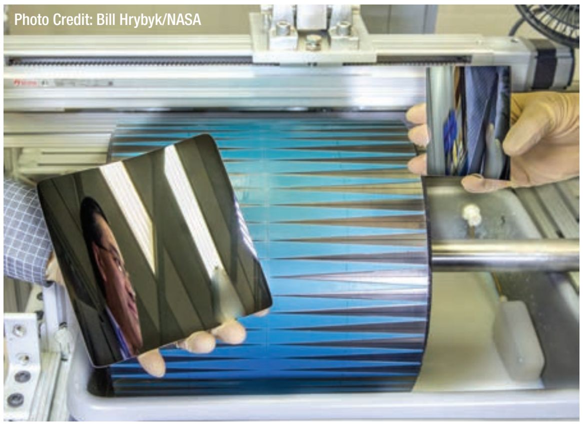
- **Venus In situ Composition Investigations (VICI)** is led by Goddard scientist Lori Glaze. With its technology-development funding, the team is maturing a camera developed by the Los Alamos National Laboratory. VICI would deploy two landers to Venus where they would analyze the planet's thick atmosphere, photograph the terrain, and sample the planet's forbidding surface.

Probe-Class Missions

In FY18, several teams advanced astrophysics concepts that could qualify as Probes, a proposed new mission class that cannot exceed more than $1 billion to complete and launch. Of the 10 studies selected by NASA's Science Mission Directorate, two are led by Goddard and others include significant participation from center scientists. Goddard's IRAD program funded others. These studies will be presented to the Astrophysics Decadal Survey for consideration in 2019. Below is a list of concepts involving Goddard experts:

- **Cosmic Evolution Through UV Spectroscopy (CETUS):** Goddard led; Headquarters funded; Principal Investigator: William Danchi
- **Transient Astrophysic Probe (TAP):** Goddard led; Headquarters funded; Principal Investigator: Jordan Camp
- **All-Sky Medium Energy Gamma-ray Observatory (AMEGO):** Goddard led; IRAD funded; Principal Investigator: Julie McEnery
- **High-Energy X-ray Probe (HEX-P):** Goddard led; IRAD funded; Principal Investigator: Ann Hornschemeier Cardiff
- **X-ray Polarimetry Probe:** Led by Washington Univesity; IRAD funded; Goddard Principal Investigator: Keith Jahoda
- **Advanced X-ray Imaging Satellite (AXIS):** Led by the University of Maryland; Headquarters funded; Goddard Principal Investigator: Andy Ptak
- **Probe of Inflation and Cosmic Origins:** Led by the University of Minnesota; Headquarters funded; Goddard Principal Investigator: Tom Essinger-Hileman
- **Starshade Rendezvous Probe:** Led by the Massachsetts Institute of Technology; Headquarters funded; Goddard Principal Investigator: Matt Greenhouse

(Investment Area: Astrophysics)



The conceptual Advanced X-ray Imaging Satellite, now being advanced as a possible astrophysics Probe mission, would use X-ray mirrors developed by scientist Will Zhang. A mirror segment is shown here.

Follow-On Funding to Advance Technology-Readiness Levels

The IRAD and CIF programs are not meant or able to provide cradle-to-grave support. Therefore, a key success metric is whether principal investigators succeed in securing follow-on funding to further advance their technologies. In FY18, these funding sources came from a variety of R&D development programs: NASA's Strategic Astrophysics Technology (SAT), Astrophysics Research and Analysis (APRA), Advanced Component Technology (ACT), Heliophysics Technology and Instrument Development for Science (H-TIDeS), Planetary

Story continued on page 15

Instrument Concepts for the Advancement of Solar System Observations (PICASSO), and NASA Space Technology Mission Directorate (STMD) Early Career Initiative (ECI).

Autonomous Multifunctional Sensor Platform

A follow-on to a past IRAD, Principal Investigator Mahmooda Sultana secured STMD ECI funding to advance a multifunctional sensor platform made of different materials using the Nanoscale Offset Printing System developed by Boston's Northeastern University. The technique could substantially simplify the assembly of sensors that typically require time-consuming handwork to wire together components.
(Investment Area: Crosscutting Technology and Capabilities)

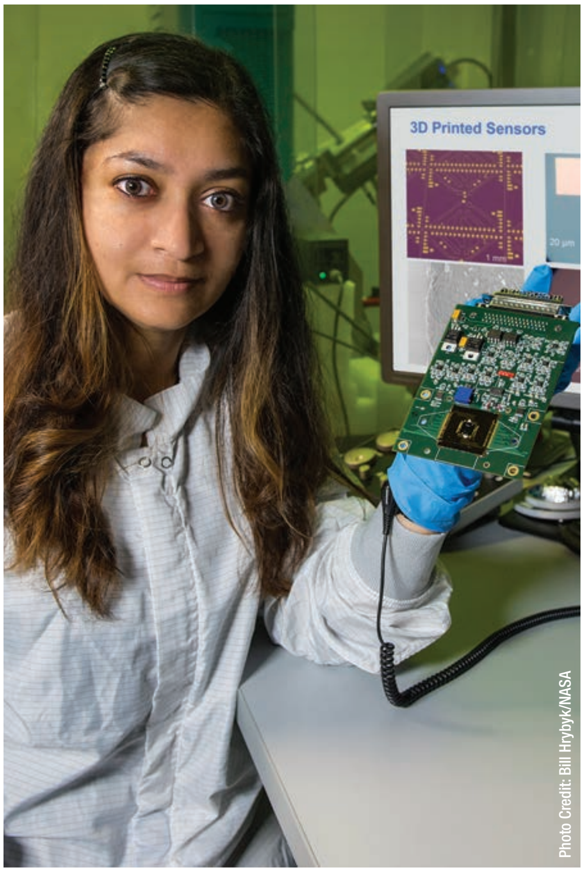
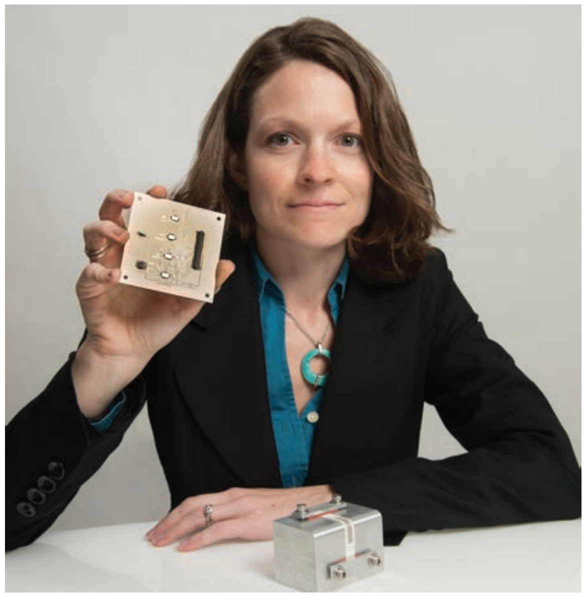


Photo Credit: Bill Hrybyk/NASA

Principal Investigator Mahmooda Sultana secured a follow-on award to further develop a multifunctional sensor platform made of different materials using the Nanoscale Offset Printing System developed by Northeastern University.

Scalable Microshutter Systems for UV, Visible, and Infrared Spectroscopy

Principal Investigator Matthew Greenhouse won SAT funding to create a next-generation microshutter array using direct-write additive-manufacturing techniques. The funding is the direct result of an FY18-funded CIF effort where Technologist Beth Paquette used the direct-write technique to print silver ink traces on a sample microshutter array. The technique is promising because instrument developers could print 3-D components that otherwise could not be built using traditional manufacturing approaches.
(Investment Area: Astrophysics and Crosscutting Technology and Capabilities)



Advances made by Goddard technologist Beth Paquette in the area of direct-write manufacturing led to the award of a technology-development award. With the funding, Principal Investigator Matt Greenhouse, with support from Paquette, will investigate the technology for creating an advanced microshutter array.

Integrated Micro-Photonics for Remote Earth Science

With his ACT funding, Principal Investigator Mark Stephen plans to replace the front-end of the CO2 Lidar with photonic integrated circuits (PICs). PICs use light, rather than electrons, to carry information. The sounder, developed by Goddard scientist Jim Abshire, would be capable of gathering carbon-dioxide measurements day and night.
(Investment Area: Earth Science)

Development of a Robust, Efficient Process to Produce Scalable, Superconducting Kilopixel Far-Infrared Detector Arrays

The primary goal under this SAT is advancing detector arrays already demonstrated on SOFIA's HAWC+ instrument. Led by Principal Investigators Harvey Moseley and Johannes Staguhn, primarily for a potential next-generation space observatory, the team is creating large-pixel, far-infrared architectures with integrated readouts.
(Investment Area: Astrophysics)

Correlator Array-Fed Microwave Radiometer Component Technologies

The ACT program awarded Principal Investigator Jeffrey Piepmeier funding to mature a multi-band correlator array that would feed a large reflector antenna to generate multiple radiometer microwave beams on Earth. The technology would improve measurements of precipitation rates, water vapor, cloud-liquid water and ice, ocean surface wind speeds, and snow-water equivalent.
(Investment Area: Earth Science)

Linear Mode Photon Counting HgdTe Avalanche Photodioide Detectors (APD) for Multibeam Laser Altimeters

Under this PICASSO award, Principal Investigator Xiaoli Sun will continue the development of HgCdTe lidar detectors started by the Earth Science Technology Office. The technology, begun nearly 10 years ago, could contribute to swath-mapping and spectral absorption lidars in the short- to-mid infrared wavelengths.
(Investment Areas: Earth Science and Planetary Science)

Advanced Net Flux Radiometer Focal Plane Assembly for Ice Giants

With PICASSO funding, Principal Investigator Shahid Aslam is developing a net flux radiometer that could help answer questions regarding atmospheric conditions on Neptune and Uranus, which NASA has not visited since the Voyager missions. The radiometer would help answer questions by measuring the upward and downward radiation flux in seven spectral channels.
(Investment Area: Planetary Science)

EUV Photon Sieves for Millisecond Imaging of the Solar Corona

A team led by scientist Adrian Daw is developing photon sieves, a novel diffracting imaging element that has the potential to provide solar images with up to 100 times better angular resolution than current technologies. Daw received H-TIDeS funding, which the team plans to use to make the sieves, measure the extreme-ultraviolet point-spread function, and efficiency during environmental testing.
(Investment Area: Heliophysics)

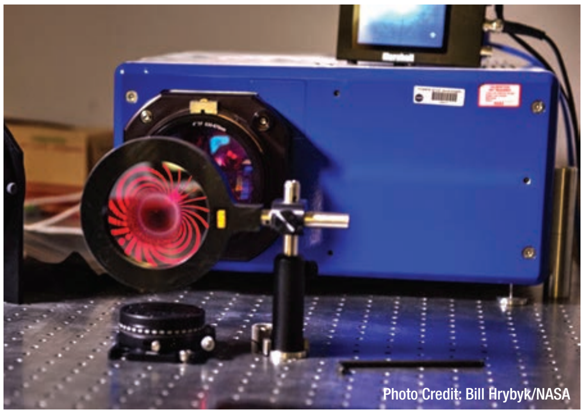


Photo Credit: Bill Hrybyk/NASA

Principal Investigator Andrian Daw received H-TIDeS funding to advance a novel diffracting imaging element called a photon sieve. It could provide solar images with up to 100 times better angular resolution than current technologies.

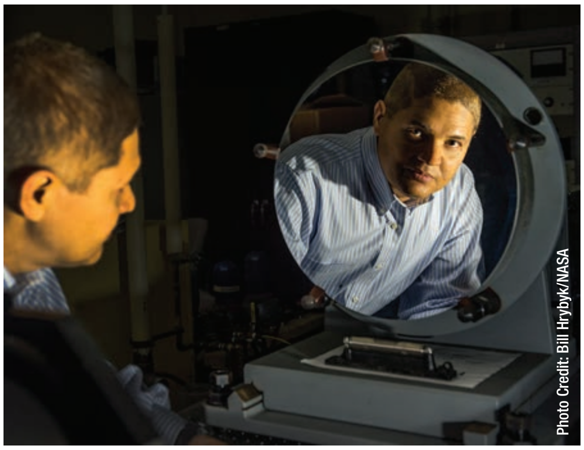
A Hard X-ray Photoelectric Polarimeter

Principal Investigator Joe Hill-Kittle will use her APRA funding to improve the time projection chamber polarimeter originally developed for the Gravity and Extreme Magnetism Small Explorer and the Polarimeter for Relativistic Astrophysical X-ray Sources Small Explorer.
(Investment Area: Astrophysics)

Development of Digital Micromirror Devices for Far-Ultraviolet Applications

In a collaboration involving the Rochester Institute of Technology, co-Principal Investigator Manuel Quijada is coating spectrographic components with a reflective coating to improve their performance in the far ultraviolet. Quijada is receiving SAT funding to carry out the effort.
(Investment Area: Astrophysics)

Story continued on page 17



Manuel Quijada is collaborating with the Rochester Institute of Technology on a reflective coating that would improve an optic's performance in the far ultraviolet.

Critical Support Capabilities

Goddard-developed technologies do not always find berths on spacecraft or instrumentation. Their sole purpose is assisting scientists in the interpretation of data or providing NASA with capabilities needed to fly missions.

Complementary Bayesian and Machine Learning Toolbox (CoBALT)

CoBALT, funded through an FY18 IRAD, is a set of codes that automatically detect and characterize gravitational microlensing events and other significant exoplanet observations. This capability could hasten the time it takes for follow-up ground- and space-based observations. The team, led by R.K. Barry, plans to deploy the codes to observatories in New Zealand and South Africa in the support of NASA's Transiting Exoplanet Survey Satellite and Wide Field Infrared Space Telescope missions.

(Investment Area: Astrophysics)

MMS and DSM Mission Modeling

Principal Investigator Terry Smith used his FY18 IRAD to develop a modeling capability that produced higher-quality, early-phase mission designs for engineers using Goddard's Mission Design Laboratory. As a result of Smith's work, the technology will be offered to mission planners to improve Goddard's competitive posture in the future.

(Investment Area: Crosscutting Technology and Capabilities)

X-ray Pulsar Navigation for Crewed Exploration of Cis-Lunar Space and Beyond

TIn November 2017, a Goddard team demonstrated in an experiment called Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) that it could use millisecond pulsars to accurately determine the location of an object moving at thousands of miles per hour in space. To expand the technology's use in future manned and unmanned missions, the SEXTANT team delivered a hardware-in-the-loop testing capability to the Johnson Space Center's Orion Optical Navigation testbed. Other potential collaborations involving X-ray navigation include the Lunar Orbital Platform-Gateway and the Evolvable Mars Campaign.

(Investment Area: Planetary Science)

The team that demonstrated fully autonomous X-ray navigation in space — a capability that could revolutionize NASA's ability to pilot spacecraft to the far reaches of the solar system — included (from left to right): Wayne Yu, Sean Semper, Jason Mitchell, Luke Winternitz, Munther Hassouneh, and Sam Price.

Advancements in Optical Navigation Capabilities

Principal Investigator Andrew Liounis successfully advanced Goddard's optical navigation capabilities by adding new algorithms and improvements to the Goddard Image Analysis and Navigation Tool (GIANT), an in-house-developed software suite for performing precision optical navigation for all mission types. The CAESAR mission (see page 13) has already begun funding further enhancements.

(Investment Area: Communications and Navigation)

Mixed-Reality Engineering Toolkit (MRET)

Under this follow-on IRAD award, Principal Investigator Thomas Grubb created a common infrastructure, called MRET, for engineering-related virtual-reality applications. The tool helps in all phases of concept design, from pre-Phase-A and hardware integration to test planning and execution. Because of the tool's development, Grubb and his team are able to support multiple engineering domains and leverage funding to help others.

As a result of MRET's development, Grubb has established collaborations with several internal and external organizations and missions, including the Satellite Servicing Project Division, the Goddard Mission Services Evolution Center, the Community Coordinated Modeling Center, and the Science and Visualization Studio, among other groups. The tool is changing the way Goddard works, and with additional funding, Grubb believes virtual-reality tools will accelerate innovation and discovery.
(Investment Area: Heliophysics)

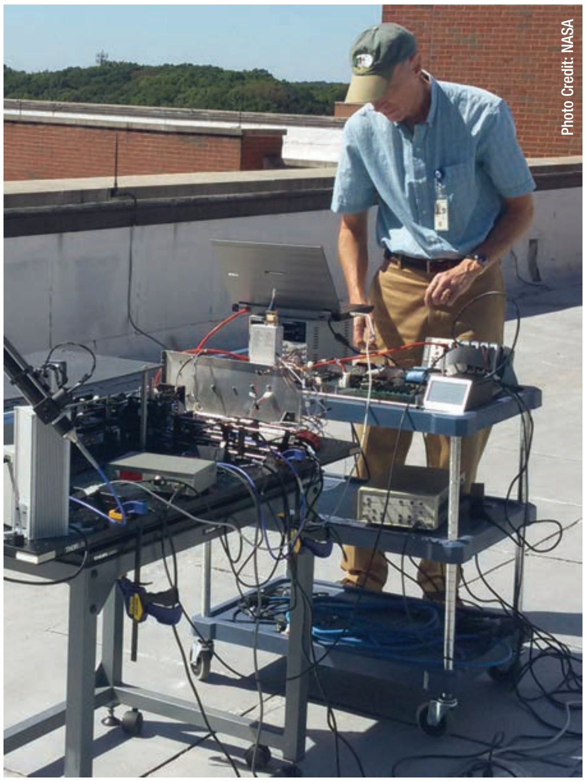
Funded under the CIF program, Principal Investigator Tom Grubb enjoyed several successes with his Mixed-Reality Engineering Toolkit, a virtual-reality technology that is reshaping the way that scientists and engineer work. A Goddard technologist is shown here interacting with the technology.

Patent Applications

Another important success metric is the filing of patent applications for technologies developed with IRAD support. In FY18, Goddard researchers filed at least two.

OH Column Measurements Field Demonstration

Although Principal Investigator Thomas Hanisco had developed a new radiometer for measuring hydroxyl — a chemical that determines the lifetime of methane, a potent, long-lived greenhouse gas — his technique did not perform as desired. However, in testing, Hanisco discovered that the instrument and observing technique are effective at measuring ozone — 100 times more sensitive than existing commercially available instruments. Hanisco has submitted a patent application and plans to further develop the technology for an in situ airborne instrument to support the Tropospheric Chemistry Program.
(Investment Area: Earth Science)



Technologist Steve Bailey helped physical chemist Tom Hanisco develop a portable instrument to measure hydroxyl, a chemical that cleanses the atmosphere of methane. During his research, Hanisco discovered that the approach was not as effective as envisioned, but serendipitously discovered that it was effective at measuring ozone. A patent has been filed.

Tunable Laser Absorption Spectrometer

Principal Investigator Kenji Numata is developing a tunable laser spectrometer that he believes could revolutionize lidar instruments, which, today can only measure one wavelength at a time. With his FY18 IRAD, Numata investigated a unique oscillator that has never before been tried with lidars and, as a result of his work, filed a patent application, Fast and Widely Tunable Monolithic Optical Parametric Oscillator for Laser Spectrometers in August 2018.
(Investment Area: Planetary Science)

Spin-off Applications

Although IRAD and other R&D programs primarily support technologies that advance NASA's missions and goals, those that help non-space-related enterprises are also celebrated as major achievements.

Molecular Adsorber Coating

Under a Space Act Agreement with the Smithsonian Institution, Principal Investigator Nithin Abraham tested the effectiveness of the patent-pending Molecular Adsorber Coating, or MAC, created originally to entrap outgassed molecular contaminants and prevent them from adhering to sensitive instruments and components. In this spin-off application, the goal was to determine whether MAC was effective at reducing the presence of mercury vapor and other contaminants that outgas from plant and mineral specimens, tainting specially designed metal storage cabinets used by the Smithsonian.

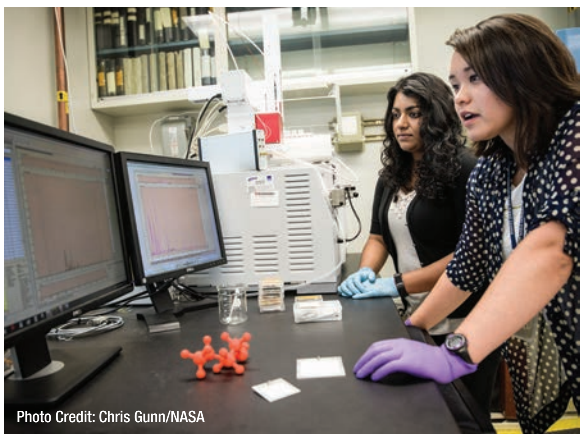


Photo Credit: Chris Gunn/NASA

Jennifer Domanowski (forefront) and Nithin Abraham begin evaluating the effectiveness of the Goddard-developed molecular adsorber coating for removing mercury vapor and other contaminants inside Smithsonian specimen-storage cabinets.

Analysis is continuing; however, initial results showed that MAC collected "very small" concentrations of a variety of chemicals. Mercury was not one of those contaminants, which Abraham said did not necessarily mean MAC had not adsorbed the chemical. Smithsonian officials are reviewing the results and Abraham is planning to pursue further testing.
(Investment Area: Crosscutting Technology and Capabilities)

Photo Credit: Chris Gunn/NASA

Goddard Thermal Coatings Engineer Nithin Abraham collaborated with the Smithsonian Institution to test the effectiveness of an adsorber coating in removing harmful contaminants from the museum's specimen-storage cabinets.

On the Path to Success: Technologies to Watch

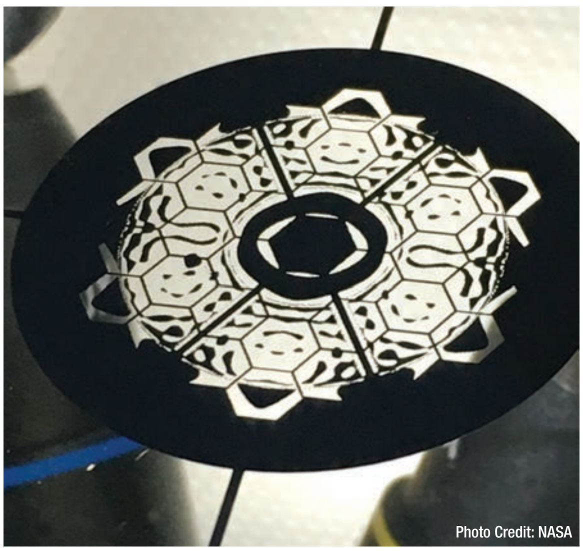
FOUR

Research and development is a high-risk endeavor. In some cases, the research does not yield the expected outcome or result. In others, the principal investigator achieves precisely what he or she set out to accomplish. Here we spotlight just a few early-stage, often higher-risk technologies that could result in Goddard creating new opportunities and helping NASA carry out its science and exploration missions.

Astrophysics

Assessment of Coronagraph Masks for High-Contrast Imaging Testbeds

Principal Investigator Ron Shiri is fabricating carbon-nanotube and black-silicon coated coronagraphic pupil masks for high-contrast imaging testbeds needed to assess the performance of next-generation planet-finding mission optics. The coatings are designed to absorb straylight. Shiri reported that to date, he and his team have achieved the most absorbent black silicon for coronagraphic masks.



Principal Investigator Ron Shiri is experimenting with carbon-nanotube and black-silicon coated coronagraphic pupil masks similar to the one shown here. The coatings are designed to absorb straylight.

Remote Occulter for the 2030s

The Remote Occulter is a mission concept led by Nobel Prize winner John Mather. Targeted for the 2030s, the mission would characterize planetary systems and exo-planets of different types and sizes. Funded by the FY18 IRAD program, the mission would use laser guide stars for adaptive optics. Mather plans to develop a white paper for the upcoming Astrophysics Decadal Survey.

Normal-Incidence X-ray Mirror for Mapping Warm Galactic Halos

Work is continuing under this effort to develop a normal-incidence X-ray mirror, which would reflect in a very narrow range and enable soft X-ray imaging spectroscopy. Principal Investigator Maxim Markevitch is studying multi-layer coating techniques to enhance the mirror's reflectivity.

Stress Distortion Free Coating for High-Resolution X-ray Mirrors

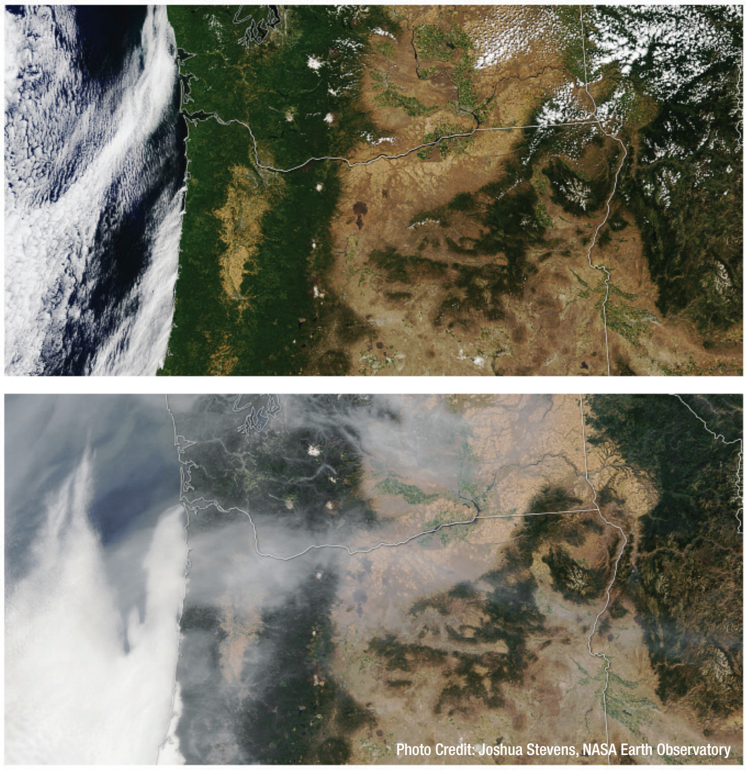
Meanwhile, Principal Investigator Takashi Okajima is experimenting with distortion-free, repeatable coatings for next-generation X-ray mirrors. His task was to find a way to coat a mirror substrate with either a single layer of platinum or iridium or multilayers that would provide high reflectivity without distorting the substrate. He reported he had succeeded with the single coating, but the multilayer technique needs more work. He presented his results at the SPIE conference in 2018.

Focus on Machine Learning

Considered a subset of artificial intelligence, machine learning and neural networks are actually in the avant-garde. Instead of programming a computer to carry out every task it needs to do, the philosophy behind machine learning is to equip ground- or space-based computer processors with algorithms that, like humans, learn from data, finding and recognizing patterns and trends, but faster, more accurately, and without bias. In FY18, the IRAD program funded several research projects under various lines of business. Some are described here.

Goddard Embedded Neural Network Library (GENNL)

Principal Investigator James MacKinnon carried out several machine-learning projects in FY18. He compiled a library of machine-learning computer models, dataset-generation tools, and visualization aids to make it easier for others to use machine learning for their missions. He also trained a neural network to find wildfires in data collected by the Joint Polar Satellite System's Visible Infrared Imaging Radiometer Suite. His work is continuing.



The Moderate Resolution Imaging Spectroradiometer, or MODIS, on NASA's Terra satellite acquired these natural-color images. The photo on the bottom shows the enormous amount of smoke produced during fires in Oregon last summer. The image on the top was taken on a clear day. A Goddard engineer has used MODIS data to train algorithms how to detect wildfires.

Improving the Skill of Remotely Sensed Snow-Water Equivalent Retrievals Using Deep Learning

Funded under the Earth science line of business, this effort also involved the use of machine learning to improve data processing. Led by Principal Investigators Sujay Kumar and Daniel Duffy, this IRAD focused on implementing sophisticated data-driven models for snow-water equivalent measurements. Kumar reported that his work could be used for other Earth science missions.

Deep Learning for Super-Resolution of Time Series Satellite Images

Under this effort, Principal Investigator Troy Ames explored how machine-learning techniques can compensate for relatively low-resolution sensors on resource-constrained platforms, such as SmallSats and CubeSats. Ames reported that several opportunities exist for the technology and that future funding is being sought under other funding programs.

Supervised Machine-Learning for Intelligent Collision Avoidance

The goal of this IRAD, led by Principal Investigator Alinda Mashiku, was developing an autonomous and reliable way that ground controllers could use to re-position space assets and prevent collisions with space objects. Under the effort, which was funded under the communications and navigation line of business, the team developed a deep learning neural network. Work is continuing.

Communications and Navigation

Onboard Wireless Networks Feasibility Study

Principal Investigator Serhat Altunc studied the feasibility of using wireless networks and sensors in instruments and spacecraft. His study assessed both the benefits and risks, determined the overall feasibility for Goddard mission applications, and defined a roadmap for the development and infusion of wireless technologies.

User Initiated Service Enabling Flight Software

Traditional mission operations and communications services are highly scripted, often planned weeks in advance. This limits a spacecraft's responsiveness to changing scientific events. A new automated software protocol — User Initiated Services (UIS) — could allow for more flexibility and greater efficiency in the use of communications resources. Principal Investigator Chris Roberts is now working to advance UIS technology and is targeting a flight demonstration, potentially on the International Space Station.

A Multi-Spacecraft, Multi-Objective Interplanetary Global Trajectory Optimization Transcription

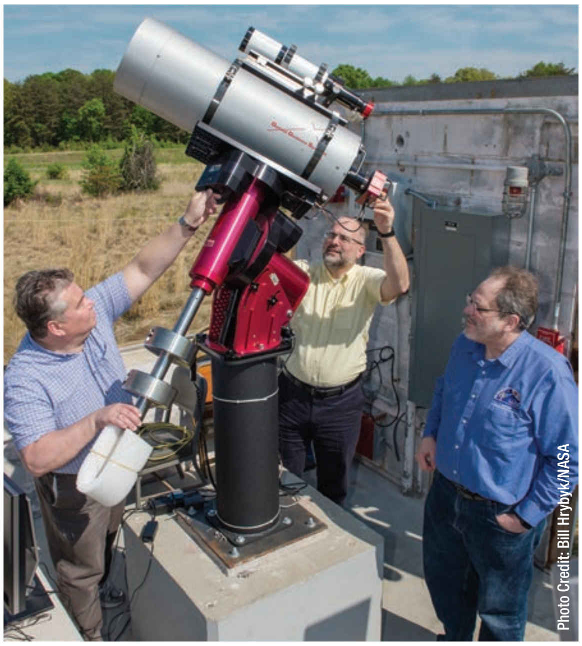
Currently no tool exists to optimally design distributed spacecraft missions. Under his FY18 IRAD, Principal Investigator Sean Napier developed first-cut designs for near-Earth asteroid and ice giant missions, involving fleets of identical co-launched vehicles. Future work will build on his accomplishments.

GPS Low Cross-Polarization Antenna Array for Orbit Determination Beyond Geostationary Earth Orbits

Under his FY18 IRAD, Principal Investigator Victor Marrero-Fontanez succeeded in developing a wideband GPS antenna and documenting its performance. The aim is to expand GPS's use beyond low-Earth orbit and use this signal for orbit determination.

Photonic Lanterns for Optical Communications

In collaboration with the Glenn Research Center and University of Sydney researcher Sergio Leon-Saval, Principal Investigator Robert Lafon and his team developed a low-cost optical ground terminal that they plan to demonstrate with a currently operating CubeSat mission. The team plans to demonstrate photonic lanterns, a technology that would eliminate the need for costly adaptive optics needed to correct atmospheric distortions that adversely affect laser communications.



A Goddard team has created a low-cost laser communications ground terminal that could help expand the use of this technology. With the terminal, the group plans to demonstrate photonic lanterns, a technology that could eliminate costly adaptive optics. From left to right: John Speer, Armen Caroglanian, and Robert Lafon.

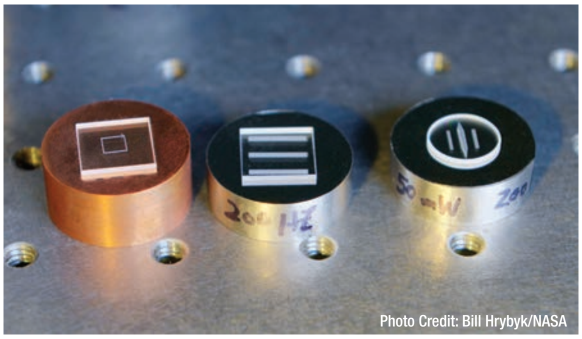
Crosscutting Technology and Capabilities

Radiation-Hardened Housekeeping Slave Node Application-Specific Integrated Circuit (ASIC)

Principal Investigator George Suarez has largely completed the design of a radiation-hardened housekeeping slave node ASIC that will allow engineers to further miniaturize instrument and spacecraft housekeeping electronics. What remains is integration and top-level simulation, which Suarez plans to do with his FY19 IRAD.

Ultrafast Laser Material Processing

Principal Investigator Robert Lafon and his team are experimenting with ultra-fast lasers to potentially revolutionize the way that technicians manufacture and ultimately assemble instrument components made of dissimilar materials. The group has already shown that it can effectively weld glass to copper, glass to glass, and drill hair-sized pinholes in different materials. Research is continuing.



A Goddard team is using an ultrafast laser to bond dissimilar materials, with the goal of ultimately eliminating epoxies that outgas and contaminate sensitive spacecraft components. Shown here are a few samples (from left to right): silica welded to copper; silica welded to Invar; and sapphire welded to Invar.

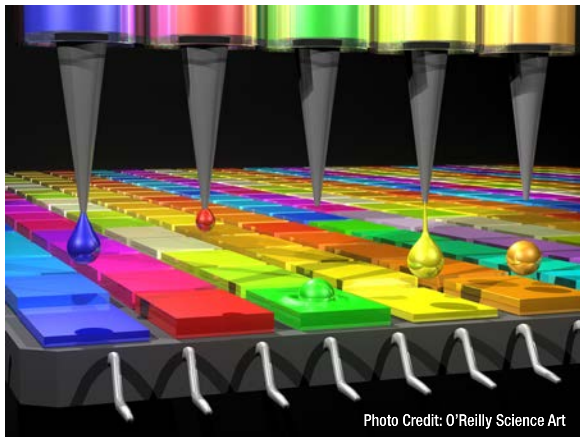
Thermal Vacuum Verification of Origami-Inspired Radiators

Working with Brigham Young University, Principal Investigator Vivek Dwivedi has shown that an unconventional radiator concept that would fold and unfold, much like Origami, is able to maintain a certain temperature, thereby raising its technology-readiness level from one to three. Further testing is required in regard to different fold angles and coating technologies.

Vivek Dwivedi, who is standing in front of a sputtering reactor used to deposit vanadium-oxide onto sample substrates for testing, is collaborating with Brigham Young University researchers to develop a radiator ideal for small spacecraft.

Quantum-Dot Spectrometers

This novel effort focused on the development of an ultra-compact, low-mass, and low-cost multispectral imager, based on the evolving quantum dot array technology patented by the Massachusetts Institute of Technology. Under this concept now being advanced by Principal Investigator Mahmooda Sultana, quantum dots act as an absorptive filter, which replaces prisms, gratings, interference filters, and other optical components currently used in spectrometers. Work is continuing under FY19 IRAD funding.



The illustration shows how a device prints the quantum-dot filters that absorb different wavelengths of light depending on their size and composition. The emerging technology could give scientists a more flexible, cost-effective approach for developing spectrometers, a commonly used instrument.

Earth Science

Digital Array Gas Filter (DAGR)

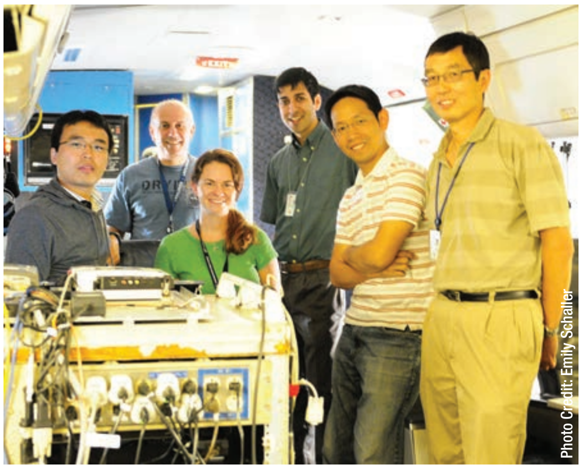
DAGR is a passive remote-sensing instrument to measure surface methane from either a CubeSat or SmallSat. Principal Investigator Paul Newman reported that he made significant progress in the instrument's design and plans to complete DAGR's assembly in FY2019, which would lead to laboratory calibration and testing and then an aircraft demonstration.

A Free-Form Optics Instrument

Under this IRAD, Principal Investigator Jon Ranson and his team conceived a small, low-cost instrument to capture 3-D vegetation structure — a research area highlighted by the 2017 Earth Science Decadal Survey. The team reported it made good progress developing a viable concept for such an instrument that could fly on a SmallSat.

Methane Lidar Transmitter Development for Space

In another IRAD aimed at advancing methane measurements, Principal Investigator Haris Riris redesigned and integrated a multi-wavelength optical parametric oscillator with a fiber laser in an attempt to advance the technology-readiness level of a future space-based lidar that would measure global methane. Work is continuing.



Principal Investigator Haris Riris is advancing a lidar system for measuring methane. From left to right: Kenji Numata, Haris Riris, Martha Dawsey, Anand Ramanathan, Stewart Wu, and Steve Li.

Assessment and Risk Mitigation Strategies for the Atom Interferometer Gravity Gradiometer (AIGG) Seed Lasers

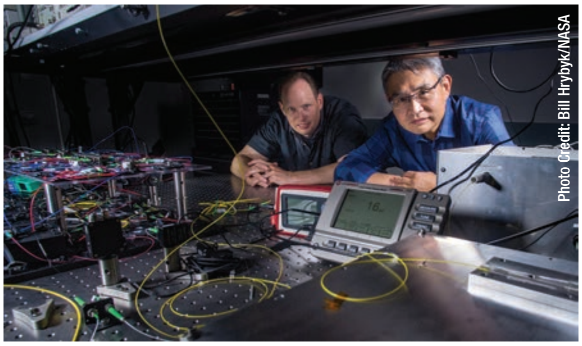
Principal Investigator Molly Fahey reported while she and her team have made significant progress developing AIGG, which uses atom interferometry to measure Earth's gravitational field, the instrument's technology-readiness level remains at about four. Her goal in FY18 was initiating a detailed assessment of the instrument's master oscillator seed lasers. Testing began in July 2018 and will continue into FY19.

Snow-Water Equivalent Synthetic Aperture Radar and Radiometer (SWESARR)

SWESARR is a three-band radar and three-band radiometer developed to improve scientists' understanding of snow-water estimates. The primary goal, which Principal Investigator Batu Osmanoglu accomplished with his FY18 IRAD, was completing the instrument's fabrication, integration, and testing in preparation for a possible snow-measuring field campaign called SnowEx in FY19. The effort is continuing.

Improving GSFC's CO2 Sounder Approach for Airborne Science Campaigns and for Atmospheric CO2 Space Missions

In addition to increasing the readiness of his CO2 Sounder for use in space, namely on NASA's proposed Active Sensing of CO2 Emissions over Nights, Days and Seasons (ASCENDS), Principal Investigator Jim Abshire used his FY18 IRAD funding to ruggedize and miniaturize his instrument so that he can also fly it aboard high-altitude research aircraft. The aircraft-compatible instrument also could serve as an airborne simulator for ASCENDS should NASA build such a mission.



Mark Stephen and Tony Yu are part of the team developing the advanced laser system for the CO2 Sounder.

Heliophysics

Development of a Neutral Wind and Temperature Instrument with Mass Spectrometry

Under her FY18 IRAD, Principal Investigator Sara Jones demonstrated a new wind and temperature instrument that includes mass spectrometry, which is a requirement for next-generation heliophysics missions identified as important by the National Research Council. Combining winds and temperature with mass spectrometry in a single instrument will reduce mass, volume, power, and costs.

Balloon Observations for Gravity Wave Seeding of the Ionosphere

Principal Investigator Jeffrey Klenzing had two goals under his FY18 IRAD. He planned to carry out a feasibility study for housing a sodium resonance fluorescence lidar instrument on a high-altitude balloon and to provide an overview of the instrument's layout. To obtain sodium measurements, the instrument would have to carry two lasers that he believes could be used to realize a balloon payload.

Planetary Science

A Robust High-Resolution Mass Spectrometer Using Heritage Technology

Goddard is known for two technologies: quadrupole mass analyzers used in multiple planetary missions and charge-coupled device cameras employed in many space telescopes. Principal Investigator Melissa Trainer wants to marry these two technologies to create a highly capable instrument for future planetary missions. She will continue her work under an FY19 IRAD.

Critical Laser Technologies for Planetary Science Missions

Planetary lander missions need instruments that comprehensively characterize surface composition. Currently laser desorption mass spectrometry, advanced at Goddard, is typically used to identify and characterize trace amounts of organic contents, but its ability to provide geological context is limited. Principal Investigator Molly Fahey is advancing two laser technologies — femtosecond and narrow-bandwidth solid-state lasers — to improve laser mass spectrometers.

A Fluidic Trap for Life Detection in Icy Planetary Environments

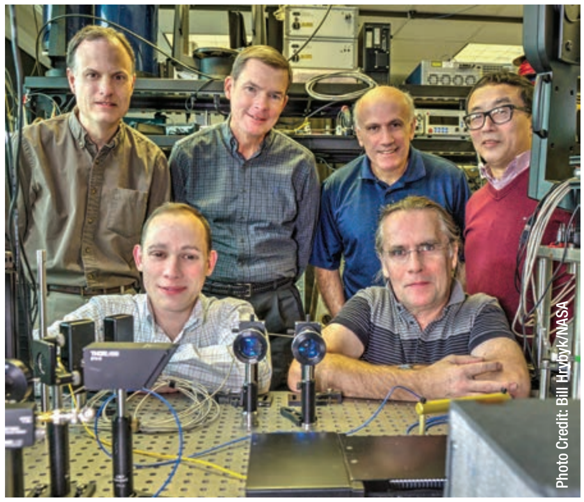
Under this task, Principal Investigator Jennifer Eigenbrode started developing a fluidic trap that would connect a fluid delivery subsystem and a gas chromatograph mass spectrometer for future planetary missions. The hardware and software are 90 percent complete. She also integrated a desalting technology developed by her colleague, Eric Parker, under another FY18 IRAD, called Development of a Desalting Capability for Life-Detection Instruments. This technology would remove relevant planetary salts in extraterrestrial materials to simplify the analysis of organic compounds that may be present.

2.5 THz Heterodyne Spectrometer

Compact and tunable THz-heterodyne spectrometers sensitive to the far-infrared submillimeter wavelengths are critical for the planetary and Earth sciences, particularly in the detection of water. Principal Investigator Berhanu Bulcha developed a state-of-the-art broadband THz mixer to help realize his vision of an instrument that could be integrated onto a Class-D CubeSat or SmallSat mission, as well as a potential lander.

Mars Orbital Water Vapor Lidar

Principal Investigator James Abshire, who has advanced a lidar instrument to measure carbon-dioxide in Earth's atmosphere, is leveraging the instrument for planetary applications. Under his FY18 IRAD, Abshire worked to extend his instrument's current wind-measurement capability to measure height-resolved winds.



A Goddard team that advanced a lidar instrument to measure carbon-dioxide is modifying the instrument to measure winds on Mars. Front row (left to right): Daniel Cremons and Graham Allan; (back row, left to right): Mike Smith, James Abshire, Haris Riris, and Xiaoli Sun.

FISHBot: A Small-Scale Autonomous Robot with Molecule Microbiology Capabilities

FISHBot is a small-scale robot envisioned as a standalone capability or as part of an instrument suite on a lander or rover. The idea is to carry out fluorescence in situ hybridization (FISH), a molecular biology technique that could identify nucleic acids on other solar system bodies. Under her IRAD, Principal Investigator Melissa Floyd built the instrument's basic mechanisms for moving samples into a chamber. She is exploring other funding programs to finish the design.

Goddard scientist Melissa Floyd holds her 3-D-printed FISHBot prototype, which she is advancing to search for bacterial life on Mars and other solar system bodies.

Science SmallSat Technology/ Suborbital Platforms and Range Services

Ion Control System (ICS)

ICS is a high specific pulse, low-thrust electric propulsion system suitable for SmallSat maneuvering. Under this effort, Principal Investigator Robert Moss set out to develop a reliable micro-propulsion guidance, navigation, and control actuator/system. Due to his work, Moss reported that the technology could be demonstrated on a Goddard-led CubeSat mission called petitSat scheduled for a FY21 launch.

DellingrX-Compatible S-Band Transceiver

Principal Investigator Wei-Chung Huang used her FY18 IRAD to develop a reliable S-band CubeSat transceiver, which includes both a transmitter and receiver, for the next-generation SmallSat architecture, DellingrX. Huang reported that both the Earth Science Technology Office and the IRAD program will help support the development of the transceiver, which has been identified as a critical need.

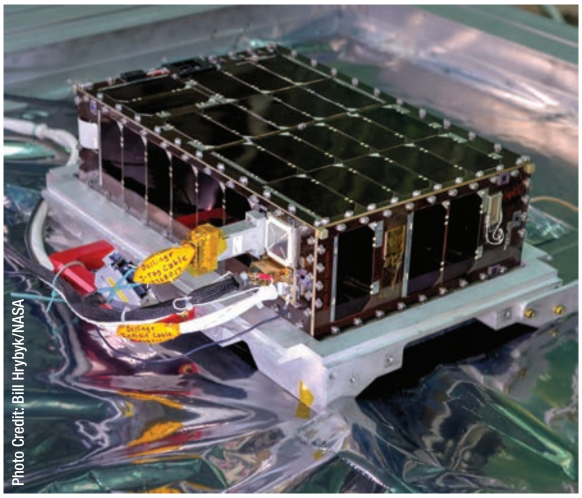


Photo Credit: Bill Hrybyk/NASA

The Dellingr spacecraft, which is gathering data in low-Earth orbit now, has resulted in the development of a more robust Dellingr architecture, DellingrX. Principal Investigator Wei-Chung Huang used her IRAD funds to develop a more reliable S-band CubeSat transceiver for this new CubeSat architecture.

CubeSat Storage and Communications Card (C-SaCC)

Low-Earth-orbiting SmallSat missions can collect large amounts of data but must downlink this data over relatively small intervals during ground passes. Under this IRAD, Principal Investigator Michael Matthews designed a 1U CubeSat-compatible electronics card to provide both onboard mass storage and a direct interface to commercially available transceivers. Pending trade studies, the technology could be implemented on currently funded CubeSat missions, Matthews reported.

Reaction Wheel for Sounding Rocket Payload Attitude Control

Sounding-rocket attitudes are currently controlled by a system involving cold gas thrusters, which potentially can interfere with science instruments. As a result, the sounding-rocket community is interested in an attitude control system (ACS) that provides fine attitude control without releasing gas. Under his FY18 IRAD, Principal Investigator Zach Peterson completed a rough design of a full ACS and expects to build and test a prototype with support from the Sounding Rocket Program Office at the Wallops Flight Facility.

FIVE

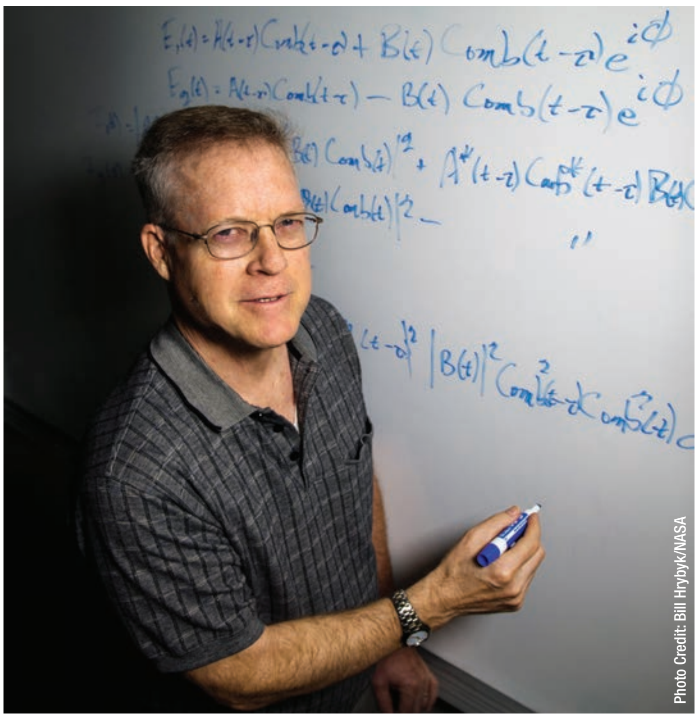
"These technology developments are **groundbreaking** and potentially transformational. I'm awed by the breadth and scope of his **technical knowledge** and **ability to envision** how NASA might use **emerging technologies** to bring about **breakthrough capabilities.** Mike is well overdue for recognition."

— Goddard Chief Technologist Peter M. Hughes

Michael Krainak Named FY18 IRAD Innovator of the Year; Team Award Bestowed on Dellingr Mission Team

The Office of the Chief Technologist selected Michael Krainak as the FY18 IRAD Innovator of the Year due to his visionary leadership and skill in applying emerging, potentially revolutionary technologies to a myriad of high-impact, agency-priority spaceflight needs.

In addition to Krainak, who heads Goddard's Laser and Electro-Optics Branch, the office awarded its IRAD Team Award to Goddard scientists and engineers who successfully conceived, built, and launched in FY18 the highly resilient Dellingr CubeSat mission, which is currently gathering scientific data and demonstrating new engineering capabilities. The Dellingr team is using lessons learned to build a more robust platform — DellingrX — that can operate beyond low-Earth orbit in a harsher radiation environment.



With the selection of Goddard technologist Michael Krainak as the FY18 IRAD Innovator of the Year, Goddard's Office of the Chief Technologist celebrated a rare combination of skills that NASA values — technical acumen, visionary thinking, and inspirational leadership.

"Mike is an innovator. He sees applications in emerging technologies and then uses his management acumen to not only secure funding to further advance the idea, but also pull together the right mix of people to work on the effort," said Goddard Chief Technologist Peter Hughes. "With this choice, we celebrate a rare combination of skills that NASA values — technical acumen, visionary thinking, and inspirational leadership.

Krainak has played an important role in NASA's Laser Communications Relay Demonstration (LCRD) mission, which will show a fully operational laser or optical communications system. He also guided the development of

"Despite a **tight budget** and aggressive schedule, this team **accomplished** this and more. The team inaugurated **a new era** for scientists wanting to use small, highly **resilient satellites** to carry out important, and in some cases, never-before-tried **science**."

— Goddard Chief Technologist Peter M. Hughes

NASA's first low-Earth-user modem, which will fly on the International Space Station and serve as a low-Earth terminal for LCRD.

Understanding that optical communications is the future, Krainak directed his organization to develop and demonstrate a low-cost laser communications ground station, with the hope that the system would lay the foundation for widespread adoption of optical communications (see page 22).

He has since emerged as the agency's expert in photonic integrated chips. His leadership in the field is one of the reasons NASA appointed him as its representative to the American Institute for Manufacturing Integrated Photonics, a non-profit consortium that brings together the nation's leading talent to establish global leadership in the field.

As the recipient of multiple patents and author of a prodigious number of technical articles, Krainak has submitted patent applications for a laser crystal that could promote more widespread use of artificial guide stars in ground- and space-based astronomy and laser communications, to name just a few applications. Patents are also pending for an ultra-low-noise laser to detect cosmic gravitational waves as well as for quantum and optical sensors.

The Dellingr Team

The office also awarded its IRAD Team Award to Goddard scientists and engineers who developed the highly resilient Dellingr CubeSat bus and a handful of miniaturized instruments, including an advanced time-of-flight ion-neutral mass spectrometer, two miniaturized magnetometer systems, a release mechanism called DANY, short for Diminutive Assembly for Nanosatellite Deployables, and a miniaturized thermal-control technology.

Lessons learned from developing the Dellingr mission contributed to the win of three additional CubeSat missions, including petitSat, GTOSat (see page 11) and BurstCube, and efforts are now underway to create a follow-on SmallSat architecture — DellingrX — which will extend capabilities beyond CubeSats and be capable of operating outside the relatively benign radiation environment found in low-Earth orbit.

Photo Credit: Bill Hrybyk/NASA

The Dellingr team overcame adversity, ultimately creating a more robust and resilient CubeSat platform. For this and other reasons, the team received the FY18 IRAD Team Award. Dellingr team members include (first row, from left to right): Traci Rosnack, Juan Rodriguez, Blair Carter, Manohar Deshpande, Luis Santos, Chuck Clagett, Michael Johnson, Larry Kepko, Nick Paschalidis, Ken McCaughey, and Paulo Uribe; second row (left to right): Wendy Morgenstern, Eftyhia Zesta, Todd Bonalsky, Jaquelyn Snell, Eric Smith, Dennis Chornay, John Lucas, Dan Berry, Tim Cameron, and Marcello Rodriguez; third row (left to right): Allison Evans, Dean Chai, Matt Colvin, Tom Plummer, Todd Bently, Eric Bentley, James Marshall, Kris Heefner, Giriraj Nanan, and Behnam Azimi.

SIX

Ending the Year with Celebration: Scenes from the FY18 Annual Poster Session

The year ended with the annual "IRAD Poster Session," which showcased the work of about 80 principal investigators and attracted hundreds of visitors.

This chapter tells the story in photos, all taken by Goddard photographer Bill Hrybyk.

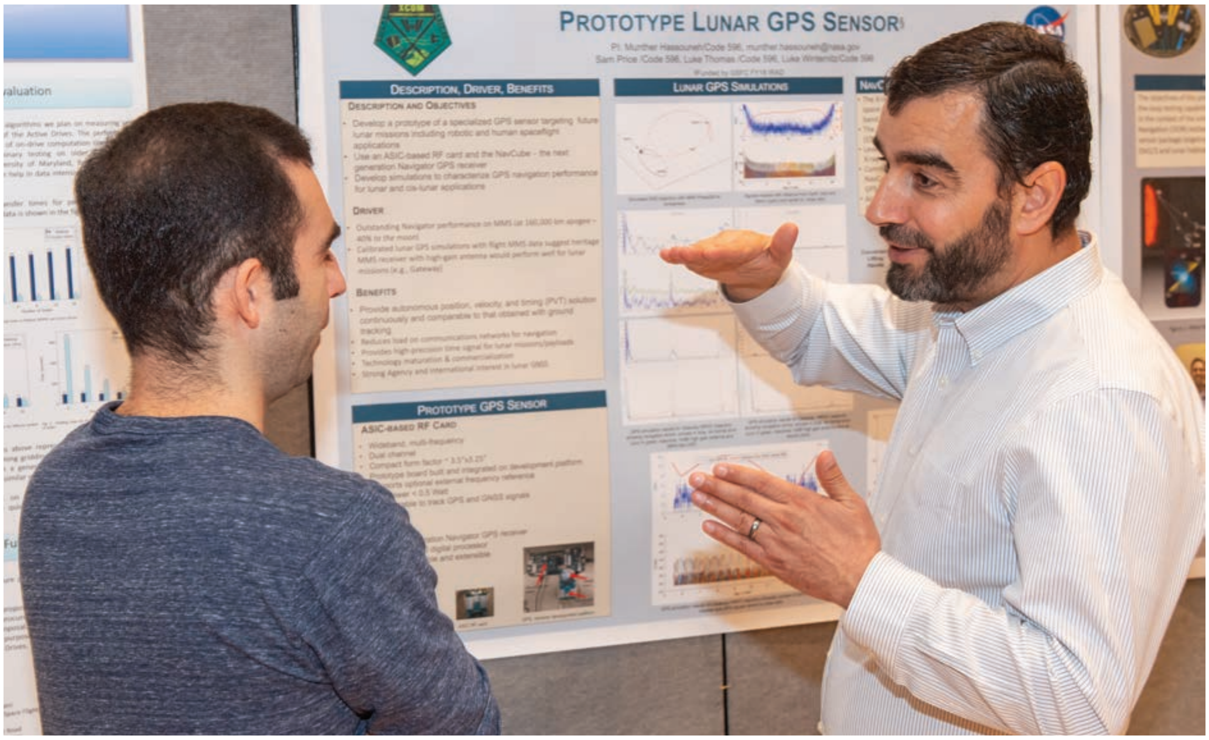
Principal Investigator Batu Osmanoglu discusses his research into the use of synthetic aperture radar to gather snow-water equivalents.

The inventor of CubeSat-compatible magnetometer systems, Principal Investigator Eftyhia Zesta, brought along one of her models to share with poster session attendees.

Principal Investigator John Sadleir is developing superconducting transition-edge sensors for a next-generation astrophysics mission. He explains his research to Goddard scientist Keith Jahoda.

FY18 Innovator of the Year Michael Krainak (left) receives congratulations from Deputy Chief Technologist Julie Crooke (right).

Chief Technologist Peter Hughes (left) and Goddard Deputy Center Director for Technology and Research Investments Christyl Johnson (right) honored this year's Innovator of Year, Michael Krainak.



In FY18, Principal Investigator Munther Hassouneh used his IRAD funding to complete the development of NavCube GPS L1/L2C receiver hardware and flight software.

The FY18 IRAD Team Award was bestowed on scientists and engineers who developed the Dellingr CubeSat platform and instruments. From left to right: Peter Hughes, Luis Santos, Michael Johnson, Larry Kepko, and Christyl Johnson.

Principal Investigator Tom Grubb (right) made significant progress in FY18 advancing virtual reality/augmented reality capabilities for engineering and scientific applications.